



National Solar Technology Roadmap: **CIGS PV**

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Scope

This roadmap addresses copper indium gallium diselenide (CIGS) photovoltaics (PV) using all types of absorber-layer processing.

Technology development stage: Prototype testing through initial commercialization.

Target applications: CIGS has potential for high efficiency for both glass and flexible PV modules. A flexible module format will make the modules suitable for many residential, commercial, and utility applications, as well as integration within building materials.

Background

The demonstration of laboratory-scale, thin-film CIGS solar cells reaching nearly 20% efficiency helped to launch numerous start-up companies seeking to “grab the ring”—namely, to develop a low-cost, thin-film product that performs as well as the best silicon-based modules. The entry point for many firms will be based on leaving a large gap between the champion device and the first product efficiencies; but these companies can enter commercial markets as long as their product can compete with the cost of other thin-film PV modules. Increasing CIGS module performance to values higher than competing thin-film PV technologies could ultimately allow CIGS to achieve the lowest module costs and levelized cost of energy (LCOE) among all PV technologies. Hence, a primary challenge is to provide the science and technology needed to close the gap in efficiency between the entry-level prototype products and champion devices. A second challenge is to discover and qualify new materials and device schemes that can enhance performance, absorber bandgap and voltage, material usage, stability, yield, and process simplicity.

Roadmap Overview

Start-up companies have selected a multitude of processing approaches, which provides both an opportunity as well as a challenge to improve commercial module efficiency. Ultimately, we need to know at what point a chosen deposition or processing approach becomes the dominant factor for limiting product performance. Building-integrated products may provide a significant entry channel for CIGS thin-film cells, taking advantage of the demonstrated capability to manufacture flexible cells (e.g., Global Solar, DayStar, Miasole, Ascent Solar, NanoSolar, ISET, and SoloPower) and the potential to conform the film PV to building-material geometries. The absence of glass encapsulation systems drives a second high-priority development to address the inherent device sensitivity to water vapor. Developing a low-cost, flexible, transparent package for CIGS that will assure long (20-year-plus) outdoor module lifetime constitutes an enabling prerequisite for addressing this business segment.

Several cost analyses place the area-related costs of manufacturing a CIGS thin-film PV module produced in an entry-level plant of 25 MW_p annual capacity in the range of \$0.75 to \$1.05/m². With efficiencies of only 8%–10%, good production yields (>70%), and sufficient product reliability to support a warranty, the manufacturers should be able to sell their modules profitably for less than \$2/W_p—which is better than what is achievable in the near-term for silicon modules and competitive with competing thin-film PV

approaches. Unfortunately, most of the new companies are not yet hitting even these modest efficiency targets or yield in pilot production and have very limited prototype products ready for reliability tests. Thus, a significant challenge is a national program that can assist commercial manufacturing of high-performance devices. Products that have been fielded by Shell Solar, Global Solar, Würth Solar, and Showa Shell have reached manufacturing efficiencies of 11% (13% champion), and acceptable reliability has been obtained for some, but not all, of these pilot products.

The ultimate impact of CIGS PV technology may be limited by the availability of indium. Estimates vary widely, but based on what is known today about In usage and In supply, a range of 2,000–10,000 MW_p of annual module production may perhaps be established as a limit. To extend these limits, it would be highly desirable to use CIGS devices with much thinner absorber layers than used today (typically, 1.4–3 microns). This would also increase manufacturing throughput because thinner layers can be deposited in less time. Implementation will require the development of thin absorber cells without a loss in efficiency, processing robustness, and module reliability. Alternatively, the family of chalcopyrite materials provides a rich set of options for engineering new absorber layers that could mimic the physical properties of CIGS needed to achieve similar remarkable efficiencies—but also add important attributes such as avoiding indium, moving to a different bandgap, increasing processing robustness, and providing a clearer path to control of properties needed.

To achieve these objectives, the following tasks must be addressed in a national CIGS program: (1) Enhance module efficiency, (2) Improve module manufacturing processes, (3) Discover alternative approaches and new materials, and (4) Assess and interact (which includes developing modeling and improved metrics).

Metrics

Parameter	Present Status (2007)	Future Goal (2015)
Commercial module efficiency	5%–11%	10%–15%
Champion device efficiency	19.5%	21%–23%
Module cost (\$/W _p)	Not established, estimated <\$2/W _p	~\$1/W _p
\$/watt installed cost	\$5–12/W _p (similar to other flat-plate technologies)	\$3/W _p
Reliability goal	0% to 6% annual degradation in pilot arrays	<1% annual power loss for commercial product
Overall process yield	Not available	>95%
New manufacturing methods	Pilot Flexible “roll-to-roll” manufacturing at Global Solar (initially packaged as a glass-to-glass laminate)	Develop new encapsulation schemes and appropriate accelerated life testing for flexible and rigid modules
Deposition rate and cell thickness	5 μm/h, 1.25–3 μm CIGS absorber thickness	30–40 μm/h <1 μm CIGS absorber thickness

Identified Needs

		University	Nat'l Lab			Industry		
Need	Significance		NREL	Sandia	Other	TPP	Incubator	Other
(1) Enhance Module Efficiency and Lower Module Cost								
(a) Comparative evaluation of production vs. high-performance CIGS devices.	(a) Increasing module efficiency from 10% to 15% can reduce module cost to <\$1/W _p with no change in production cost in \$/m ² .	x	x	x		x	x	
(b) CIGS materials and device physics: experimental and theoretical studies of complex defects, band offsets, interfaces, grain boundaries, and nonuniformities in chalcopyrites	(b) Understanding the physics underlying absorption and transport through the device will result in greater performance and yield.	x	x					
(c) Improve schemes outside the CIGS layer (e.g., grids, interconnects, transparent conducting oxides, substrate, package materials).	(c) Understanding necessary materials, devices, and processing changes to improve efficiency, yield, and reliability.	x	x			x	x	
(d) Shorter throughput from higher rates and/or lower thickness	(d) Increase rates to the 30 μm/h or greater required in vacuum processing for low equipment-depreciation rates.	x	x			x	x	
(e) Develop alternative fabrication processes, (e.g., alternative buffers, new CIGS deposition schemes, low-temperature CIGS deposition).	(e) Reduce manufacturing cost by using lower-cost and higher-performance processing.	x	x			x	x	
(f) Develop methods and	(f) Achieve greater surety	x	x			x	x	

		University	Nat'l Lab			Industry		
			NREL	Sandia	Other	TPP	Incubator	Other
Need	Significance							
metrics for assessing the value of different device-processing schemes and their scale-up potential	about the ultimate performance limit of specific processing approaches to assess cost effectiveness							
(2) Science and Engineering Base: Discover New and Alternative Approaches								
(a) Characterize and model CIGS materials and device physics, determine pathways and kinetics for CIGS materials and cell growth.	(a) Understand the factors limiting cell and module performance; improved engineering basis for manufacturing processes.	X	X			X	X	
(b) Develop improved in situ diagnostic tools	(b) Improved process monitoring and control.	X	X			X	X	
(c) Develop, characterize, and understand alternative device structures and new materials so as to increase bandgap and V_{OC} and minimize use of In.	(c) Develop new approaches to enhance device performance, minimize indium usage, or achieve better cell characteristics such as higher V_{OC} .	X	X					
(3) Assessment and Interactions								
(a) Develop protocols to assess CIGS module reliability.	(a) Implement improved or new processes by increasing the credibility of results.	X	X	X		X	X	
(b) Provide a forum that allows interactions among CIGS industry, university, and laboratory researchers.	(b) Meet manufacturers' power-performance guarantees and customer expectations. Enhance sharing of results (avoids that inconvenient results are ignored, leading to repeat mistakes).	X	X	X		X	X	